OPTIMAL STOCHASTIC CONTROL OF NONLINEAR CIVIL ENGINEERING STRUCTURES USING ACTIVE AND SEMI-ACTIVE STRATEGIES

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Introduction

Hazard Mitigation and Control (HMC) in civil engineering focuses on performance improvement, safety, and cost-effectiveness of structures mainly through

- Minimizing large deformations of seismic/wind-excited structures
- Suppressing the damage and collapse in dynamic structures due to excessive vibrations

The **decision making strategy** in HMC is based on several criteria:

- Control device: active, semi-active, passive
- Control strategy in active and semi-active systems
- Control performance
- Degree of reliability and robustness

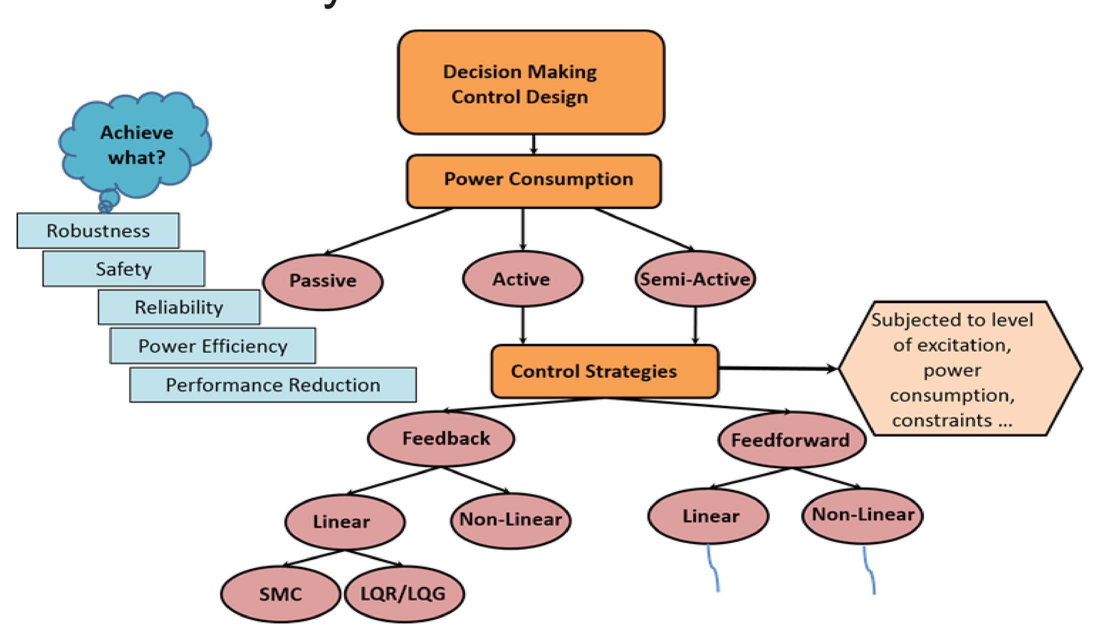


Fig. 1 Decision Making Process in Control Design

Aims

The goal is to develop and evaluate control methods that lead to more resilient designs for various civil engineering structures. The method should

- Reduce the displacements, drifts, accelerations of tall structures
- Decrease the impact of pounding of adjacent structures such as multi-span bridges
- Optimize the reliability of the structure and power efficiency of control devices

This research addresses different aspects of HMC challenges

- Adaptation to sudden events by considering stochasticity and nonlinearities in different components and excitations
- Minimization of retrofit costs of structures
- Optimization of power consumption of control devices

By

- Characterizing the system based on stochastic and nonlinear equations rather than using convectional linear deterministic strategies, and
- Providing a bounded optimal solution for constrained control devices

Methods

In conventional control engineering research, a system is linearized deterministically, then the control device is further optimized based on a linear feedback control algorithm. In the proposed framework, control design is based on both nonlinear characterization and stochastic linearization in order to capture the dynamics of the system. The proposed control algorithm captures **nonlinearity** of structures as well as **uncertainties/stochasticity** in excitations and structures

$$\mathbf{u} = f\left(\boldsymbol{x}, \boldsymbol{x}^2, \frac{\boldsymbol{D}_{\boldsymbol{x}}^{\alpha}}{\boldsymbol{Dt}}, \xi(\boldsymbol{t}), \boldsymbol{E}\right)$$

The control force stated earlier is optimized based on **convex objective functions**, which is further applied on the system in order to mitigate the vibration. The derivation is based on a **second level optimization** in order to determine the coefficients of the **objective function** and incorporate a clipping strategy that considers the device **constraints**.

Results

The methodology stated in the previous section is implemented in a shaking table test of a three span bridge shown in the figure below. For seismic pounding mitigation, an **Magnetorheological** (MR) damper manufactured by Lord Corporation, USA, is installed between adjacent spans for the passively and semi-actively controlled bridge. The control optimization is conducted on the MR damper, where a current value is computed at optimal conditions.

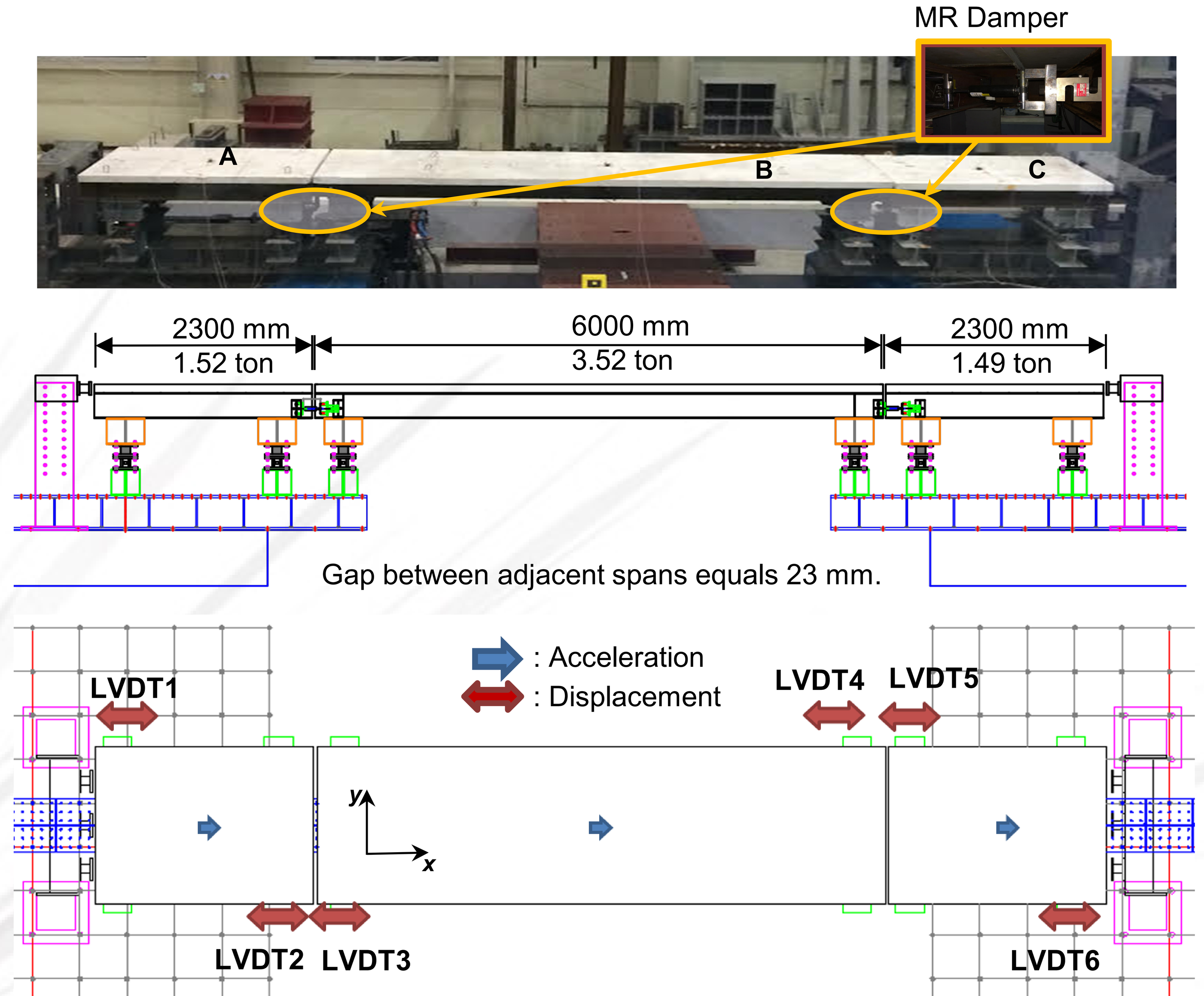
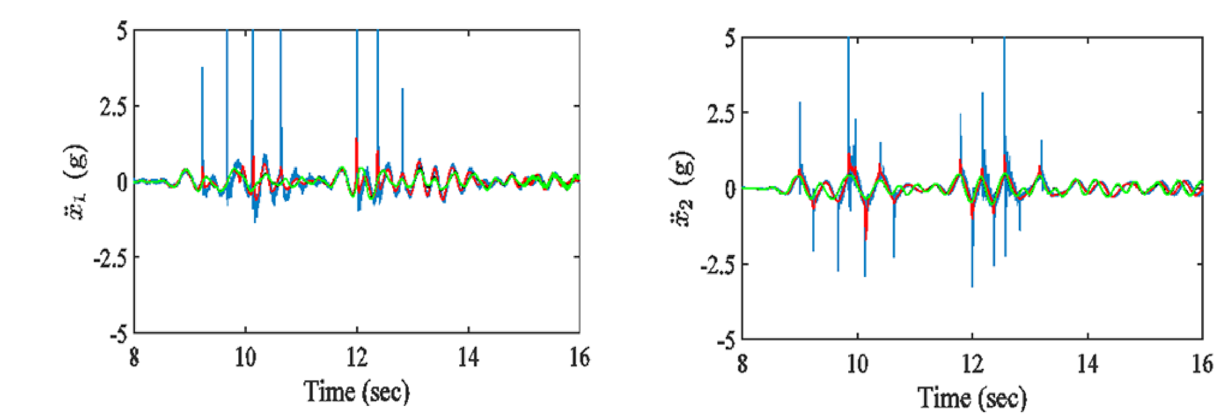
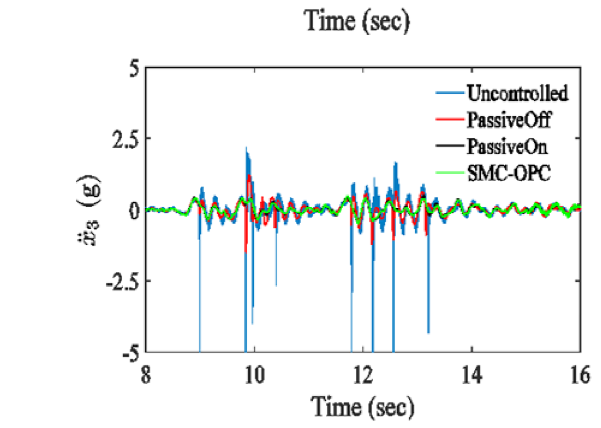


Fig. 2 Three Span Bridge





State	Critical Disp. (mm)	
	x_{12}	x_{23}
UNC	28.88	30.31
P.off	25.99	33.68
P.on	15.70	19.49
SMC-OPC	16.97	20.48

Fig. 3 Absolute Accelerations of each span subjected to Kobe 40 for uncontrolled (UNC) passive-off (P.off), passive-on (P.on), and semi-active (SMC-OPC)dampers

Conclusion

- The developed methodology is applied using semi-active MR dampers. This was shown to be successful in reducing pounding between adjacent spans.
- Critical response variables are minimized with reduced power consumption as compared to passive-on (e.g. 20-40% reduction in displacements, compared to uncontrolled, at a 60-70% power reduction as compared to passive-on).
- The installation of MR dampers between adjacent structures is capable of reducing damage due to pounding and excessive gap openings in adjacent structures.

Bibliography

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